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ABSTRACT

At present, computer-assisted instruction (CAI) is perceived as an educational breakthrough, promising a radically new kind of learning. When the goals of CAI are considered, however, it becomes clear that this view is wrong and counterproductive. If computers are to help provide efficient, effective, individualized instruction, they must be integrated within the general structure of education and applied as means to accomplish the learning ends dictated by that general structure. Such an integration of computers into the established educational enterprise would result in certain changes in the nature of computer development and computer developers. (Author)

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Abstract

At present, computer-assisted instruction (CAI) is perceived as an educational breakthrough, promising a radical new kind of learning. When the goals of CAI are considered, however, it becomes clear that this view is wrong and counterproductive. If computers are to help provide efficient, effective, individualized instruction, they must be integrated within the general structure of education and applied as means to accomplish the learning ends dictated by that general structure. Such an integration of computers into the established educational enterprise would result in certain changes in the nature of computer development and computer developers. Curriculum developers, computer and otherwise, are the intended audience for this paper.

PUTTING COMPUTERS INTO EDUCATION[1]

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Introduction

Implicit in the mission of prescribing a future for computers in education is a criticism of the present. If the present state of affairs were satisfactory and if everything were being done that ought to be done, then the future would be a straightforward extension of a rosy present and there would be little motivation to worry about it. There is reason to worry, however, for there is a condition in present educational computer development which will retard its advance and make future applications of computers in education less effective than they might be. This condition is its isolation from the mainstream of educational research and practice. Our vision for the future is the abolition of CAI as a field and the incorporation of computers into the standard lines of educational research and development.[2]

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[1] This is a revised version of a paper given at the meetings of the American Educational Research Association, New Orleans, March 1973. The author expresses his appreciation to Dr. Robert Glaser, whose thoughtful criticisms of early drafts of the paper were extremely helpful.

[2] Throughout this paper, we use CAI as a generic term for all educational applications in which the student is directly affected through an interaction with the computer. This would exclude data storage and management in which the student does not take part, but it includes practically everything else, including computer testing and computer management in which the student is given data in order to make his own instructional decisions. We view diagnosis, decision making, and instruction as important interacting components of education.

This isolation of CAI as a separate discipline with relatively little contact outside itself has a fairly clear historical genesis. The case for using computers for education usually starts with the premise that present educational practices are beset with serious difficulties. Students are not learning what they need to learn and, in addition, are acquiring a distaste for the educational process. Furthermore, no remedy for this problem seems feasible within the range of standard educational practice. The computer, however, is new and different. It offers unique features, impractical in any other medium, which are extremely important, if not essential, in solving education's problems. Typically, these unique features of CAI are described as individualization and immediate responsiveness.

Thus, a dichotomy is drawn between an outmoded, insensitive traditional educational system and the new, individualized responsive education offered by the computer. Shaplin (1967) has described this stark portrayal of a dichotomy as the "breakthrough complex." It follows from the premise of this dichotomy that computer work (research, development, implementation) should be isolated from the other old-fashioned part of education. Such work entails developing the unique ways that a computer can be used to teach and, in particular, developing the special computer properties of individualization and responsiveness. The perceived outcome is the creative production of a new kind of individualized learning, different and superior to the old group learning.

This dichotomy is largely implicit and we suspect that no producer of CAI would actively subscribe to it. Yet it is there and is evident in the existence of CAI research centers, conferences on computer education, and books and journals written by and for CAI workers. CAI is studied and developed as if it were a separate discipline with its own particular objectives. Thus, a new computer system to teach mathematics will tend to be categorized as computer instruction not math instruction and will be judged not so much on how well it teaches mathematics but on how well it approximates the ideal of "Computer Education." There is a continuing drive to develop the computer as a unique and separate medium of instruction (Anastasio & Morgan, 1972), and a tendency to judge CAI efforts not simply by how well they teach but also by how well they match an esthetic ideal of what computer education ought to be (Pask, 1972).

". . . we have put the cart before the horse. Surely, except for experimental purposes, we don't want to develop curriculum simply because it lends itself to computer-programming. Good curriculum comes first. Then the job is to see what subject matter and approaches can be best handled by the computer [Wilson, 1970, p. 263]." As we see it, the task of all educators, whether they use computers or not, is to develop this good curriculum, and compared with this task the technical considerations of implementing it on a computer are of little importance. The thesis of this paper is that the computer is not a "breakthrough" by which the standard problems of education can be avoided but a tool which can help in our attempts to ameliorate these problems.

In the first section of this paper, the major objectives of CAI will be considered. It will be demonstrated that the attainment of these objectives is possible only if computer development ceases to be isolated and becomes part of the general educational endeavor. In the second section, we will try to describe what future CAI development will be like as a component of education in general.

The Goals of Computer Education

The rationale for CAI development has rested on three predicted benefits of computer education. First, and obviously, computers should provide an effective learning environment--computers should help students learn. Second, it should be possible to use computers to adapt instruction to the particular needs of any given student. Third, this effective adaptive instruction should be producible at an efficient cost. We will consider these goals more closely and examine the conditions required to attain them.

Making Computer Instruction Effective. The case for using computers in schools is very compelling. A machine which can present complex symbolic and graphic displays, can put these displays under student control, and can adjust the nature and sequence of such presentations according to complex decision rules ought to be a very effective instructional medium. These virtues of computers are only potential, however. Effective CAI depends on specific lesson procedures which utilize this potential.

These specific methods are simply those procedures by which people are induced to learn. After failure on skill X, for example, a computer lesson can branch to either Instruction A or Instruction B. Which of the two is specifically programmed is determined by which causes people to learn best in this particular situation. In order to make computers teach, we need to find out how people learn. Otherwise, the potential of the computer cannot be channelled into specifically effective programs.

There are two related disciplines which have been concerned with the general question of how people learn. One, the psychology of human learning, has been concerned with developing a science which would explain the phenomenon of learning and would specify reliable rules by which learning takes place. The other is the technology of education which has been occupied with the development, testing, and cataloging of techniques which produce learning outcomes of practical concern. These two traditions have developed methods of study, conceptual schemes, substantive knowledge, and expert practitioners which can be invaluable in developing educational uses of computers.

If CAI development is isolated and outside these two disciplinary structures, there is bound to be redundant effort and slower than optimum progress. Computer lessons will be more reliably effective if they are consonant with the most up-to-date scientific knowledge about learning. They will be more creative and insightful if they are based on the accumulated experience and intuition of the educational enterprise. The benefits should flow both ways. Computer lessons will be better, based on scientific knowledge of learning, but on the other hand, the science will advance based on the data derived from computer learning. Likewise, conventional educational practice can guide computer lesson development, while computer lessons can provide ideas to be used in more conventional education. Thus, the goal of producing effective education with computers will be achieved not by looking at CAI as a breakthrough but by purposely fitting it into the discipline structures already developed for the study and production of learning.

<u>Individualizing Instruction with Computers</u>. Another objective of computer development work, related to that of educational effectiveness, is the creation of education which is adaptive to individual differences. Thus, not only should CAI be effective on the average, it should contain provisions for distinguishing individual student needs

and tailoring instruction to meet these needs. As is the case for the objective of educational effectiveness, it is apparent that the computer has the potential for meeting this objective, but that actualizing this potential will require the determination of relevant individual differences and the types of individual treatments appropriate to these differences.

The determination of these individual differences and their interaction with instructional treatments has proved to be a difficult problem (Cronbach & Snow, 1969), and its solution will require careful and detailed scientific work. Simply offering a computer and proclaiming that it can individualize will not solve this problem of how to individualize. Thus, again, it is clear that the CAI goal of individualized instruction requires that CAI development be integrated into the structure of the discipline already concerned with the problem of individual differences.

The goal of individualization requires further that CAI be a component within a general structure of educational implementation as well. Computers cannot be expected to present all the instruction a student receives. Students will continue to learn from textbooks, lectures, discussions, and many other sources. An important dimension of a totally individualized system will be the selection from among these components of that alternative which is most appropriate for an individual student at a given time.

Developers of CAI have concentrated their efforts on programs which are internally adaptive and have tended to ignore the challenge of specifying how their products would fit into an entire individualized system. In order to do this, CAI must be considered within the total context of all instructional alternatives. Comparisons must be made between these alternatives, and plans for matching students to optimum alternatives must be determined. This implies further that the details of specific alternatives (e.g., the particular problem presented in a CAI math program) could be changed to meet the requirements of this general overall plan. Again, it is clear that if CAI is to be used to foster individually adaptive instruction, it can do so only as a component whose development is determined by a general educational framework.

Making the Cost Feasible. The third goal of CAI which is used to justify its development is the delivery of this individualized instruction at an efficient cost. School resources are severely limited and at present the cost of CAI goes beyond these limits. Nevertheless, it is argued that other approaches to individualization can be even more expensive than CAI (Suppes & Morningstar, 1972) and that computers will become cheap enough within the foreseeable future to make CAI practical (Alpert & Bitzer, 1970).

The goal of maximally efficient individualized instruction, however, will require more than simply determining that a computer can teach a certain subject matter and do it at an affordable price. The best use of limited resources depends on knowledge of both relative costs of different teaching methods and relative benefits of the outcomes. Limited resources, including limited computer resources, can then be applied not simply where they have the greatest effect but where they have the greatest effect relative to other instruction. For example, a school planner may decide not to use a good computer spelling program because workbooks are almost as effective and the computer time which is thus freed can be devoted to a math tutorial program which other teaching methods are less able to match.

For some computer instruction, this cost-benefit evaluation can operate by a strategy of systematic reduction. Kropp (1970) has suggested this reduction in terms of hardware--using cheaper machines, such as slide projectors, to approximate instruction initially designed for computers. This reduction, however, need not be restricted to machinery. For example, a computer program may teach diagnostic techniques in medicine by allowing the student to make physiological tests on a simulated patient and from the results of these tests make a diagnosis. This instruction can be reduced to paper and pencil by giving the student a written description of the patient and inviting the student to suggest tests that should be administered. The student turns the page and reads the tests which would be most appropriate initially and is given the results of these tests. The student can compare his test proposals against the recommended set, and then from the given test results suggest additional tests and repeat the process. Whenever he is ready to make a diagnosis, he can write it down and consult the back of the book where the correct diagnosis is given. This instruction approximates the computer instruction in that it allows the student to actively engage in an individual project of diagnosis and to receive feedback of sorts for his work. It is, however, a clear reduction from the original computer program and presumably students at the computer would do better than students with the workbooks. Do they, however, do enough better to justify the use of expensive computer time?

Systematic reduction is just one way that alternative, cheaper instruction can be produced. Traditional classroom methods are by no means entirely ineffective alternatives to CAI, and new curriculum and classroom management systems are being developed which continue to increase individualization and enhance learning (e.g., Beck & Mitroff, 1972; Resnick, Wang, & Kaplan, 1970). What is needed is a systematic development and implementation in which all these possible alternatives are considered and resources put into those projects which promise the greatest payoff relative to alternatives. In other words, if a goal of CAI development is the production of maximally efficient individualized instruction, then such development must be a part of general educational development.

The Future

What, then, would future education be like with computers as members of the orchestra rather than as solo instruments? The speculation here is in terms of form and structure and not content. What is offered is an organization in which, hopefully, computers and other educational techniques can be developed to their fullest potential for teaching. To do this, it is important to not fetter ourselves with preconceptions about content but to be opportunistic and follow freely good new ideas as they develop.

Within the changing pattern of elementary and secondary education, there are three roles or functions which will remain in some form or another. First, there is the function of student tutoring and supervision, which is presently carried out by the classroom teacher. No matter what type of change, including abolition, there may be in the classroom structure, we can presume there will be some agent of the educational establishment who offers personal instruction, who makes low-level, day-to-day educational decisions, and who has immediate responsibility for a group of students. The second function is that of curriculum supervision. This function consists of developing learning resources and organizing them into a coherent program to be used by the student tutor-supervisor. This role is presently filled by curriculum developers working in industries and universities and curriculum specialists in school systems. The exact nature of the interaction between these two functions can vary and need not be specified. The point is that educational decisions are made at two levels. First, a general plan is adopted, then it is actually applied and adapted to specific students. Finally, there is the third function, that of research whereby the pool of knowledge used to make decisions is increased. This research is presently carried out in various ways, but the general goal is to gather accurate, reliable information about learning to be used by educators whose job it is to produce learning. We look at the future of education in terms of each of these functions.

Research. Research premised on the existence of a special kind of individualized computer learning is misdirected. Research work of the future will be organized, not by the medium by which it is presented (computer or non-computer) but by the learning outcome of interest (reading, elementary mathematics, and so on).

Computers used in this way, as means rather than ends, will have a far greater influence than they do now. For although computers can be marvelously useful research tools, their influence is little felt outside, what must be admitted, is a small circle of computer enthusiasts. When they are used by researchers to look at general problems of learning, they will be highly effective, and the fruits of this effectiveness will be apparent not just in instruction presented via computer but in all types of instruction. The information to be gained by using computers to study basic learning will be used to produce better computer instruction and better classroom instruction.

As an example of how computers will fit into future research, consider the use of perceptual imagery and manipulatives in the development of basic mathematical concepts. Most math educators feel that displays of some sort, which physically exemplify mathematical concepts and operations, are vital in learning these concepts and operations. For example, Dienes blocks concretely instantiate place-value notational systems, and number lines can demonstrate properties of negative numbers. Thus, there is much interest in such questions as, what are the best kinds of perceptual displays, what is the process by which an abstract concept is acquired from a physical example, at what point is a student ready to understand and use the abstract notation without the displays, and what is the range of individual variation among learners for all these questions.

Research into these questions could be greatly aided by computers. The graphic display capabilities of modern terminals allow for the presentation of many types of pictorial displays, some of which need not be stored but can be generated to meet the specifications of any problem or situation selected by machine or student. A program could be written, for example, which could produce several types of graphic representations for any given problem. These displays could be sequenced, mixed, put under student control, or otherwise combined to meet any experimental purposes and then used with a list of problems from which individual items are selected on the basis of hierarchical sequencing, student response history, or whatever else might be desired. This is one of several types of programs which would be used to study the effect of specific types of perceptual models on the learning of abstract mathematical ideas.

The advantages of using a computer for this kind of research are clear. The nature of each type of display can be precisely determined so that each repetition is identical. The sequencing of different types of displays, or no displays, can also be precisely determined according to very complex selection rules and/or put under the facile control of the student. Finally, changes can be made quickly and easily in the displays, or in the sequence of the displays to meet the needs of new experiments or newly determined individual differences.

One major shortcoming of computer research in this area is also clear. An important property of many physical models used in mathematics is that they are manipulable. Terminals with touch-sensitive surfaces or light pen inputs allow a manipulation of sorts but nothing as flexible as the rearranging, sorting, and juxtaposing which small hands can impose on a set of blocks. This is a difficulty which present technology does not allow us to overcome, but that does not mean that interesting research into physical models cannot be done with computers. The purely visual properties of models can be studied, the student can perform certain crude manipulations by making commands (by typing, touching, or using a light pen) to change the display, and situations can be arranged in which the student has both manipulable blocks and an isomorphic computer display. All the questions we wish to ask about physical models of mathematical ideas will not be answerable with computer research, but some of them may well best be answered that way.

The fundamental point here is that decisions about how to use the computer in this research will be determined entirely by the goal of discovering how perceptual models, in general, affect the acquisition of mathematical concepts. Where computers are useful they will be used, and where they are not they will not be. There will be no proprietary interest in exploiting the computer or in justifying preconceptions about its superiority.

Curriculum Development. The second major role is that of developing a general plan of instruction to be applied by a teacher. This is the role of curriculum development. Often this consists simply in writing or selecting a textbook which a teacher uses and supplements as he sees fit. Some modern work consists of developing a more varied program of textbooks, individualized workbooks and projects, audio-taped lessons, and small-group games. These and other components are organized into a coherent structure with rules of management which allow a teacher to coordinate the position and progress of individual students through the curriculum.

It is this type of curriculum development into which we see CAI fitting quite effectively. It is the developer's job to consider what is known about learning and then to put these resources together to produce an optimally effective curriculum. One of these resources will simply be a computer. There will be no isolated development of CAI lessons outside the context of general educational development, carried out by special computer people. The people who produce CAI will be the same people who produce all the other instruction and their interest will be in getting students to learn, not in getting them to learn on a computer.

Consider how an elementary mathematics curriculum might be developed. Certain objectives are defined for the curriculum in terms of the mathematical concepts, problem-solving abilities, inquiry skills, computational algorithms, and other skills which it is supposed to impart. Then a survey is made of the learning conditions which must be present in order for these skills to be learned. Finally, all the ways of producing these conditions are considered. There are textbooks, organized discussions, workbooks, blocks, and many other types of manipulative materials, and there are computers.

Decisions are made concerning the best way to use these materials to reach the learning objectives of the curriculum. Lessons or learning sequences are planned for each type of material where they are needed. The objectives of the curriculum and knowledge about how the learning objectives might best be achieved guide specific decisions about what materials to use and how to use them. For example, Dienes blocks would be used to teach place-value notation because of their appropriate perceptual qualities; computational algorithms would be taught largely with group discussions and practice sheets because verbal exposition and practice produce the optimal learning of such skills; and inquiry and problem-solving skill would be taught using particular types of interactive computer routines which can respond to an individual's needs by generating the right kind of problem with the appropriate assistance available.

Although these separate components of the curriculum can be tested separately and interchanged with other comparable components, they are all integrated into a coherent unit. This means that formats and language are standard so that, for instance, when a student goes to work at a terminal, he readily understands the information presented.

It means that examples and constructs can be shared for pedagogical efficiency, so, for example, computer problems can be illustrated with pictures of Dienes blocks which it is known the student is already familiar with, or reduced versions of discovery problems can be used on paper since students have had experience with the interactive variety at the computer. Finally, it means unnecessary redundancy is avoided, since each lesson is developed in full knowledge of what other lessons are also teaching. Thus, a student won't waste time on both computer practice and workbook practice--he'll get one or the other.

One limitation that the developer must face is that his best ideas will be well beyond the means of educational institutions to pay and he must restrict himself to a curriculum which has a reasonable cost. On the other hand, the developer must not be an obstacle to progress. He cannot ignore the practical limits, but he must push them by presenting curriculum plans which, although beyond present resources, have clear educational benefits. A given curriculum can have several alternative models depending on price and educational outcome. The best curriculum might be beyond the means of any present school and stand as a model and arguing point for the future. Simplified, immediately adaptable versions of the same curriculum could be also produced, for example, by substituting paper-and-pencil practice for computer practice or reducing the amount of diagnostic testing.

This multiple-level approach is important for the rational development of computers within the curriculum. The simpler versions of a curriculum will depend less on computers in acknowledgment of their expense. The better, more expensive levels which make heavier use of computers and expensive terminals will serve as an incentive to computer manufacturers to reduce costs and to political bodies to invest more in educational computing. A good, complete curriculum which makes systematic and purposeful use of a computer is a much better rationale for getting the computer into the school than is an admittedly effective but independent, unconnected computer program.

Curriculum Application. Finally, there is the role of student tutor and supervisor. It is this person's job to apply the curriculum to actual students and, in so doing, supplement where the curriculum is not specific, adapt or edit where the curriculum seems to be failing, and, of course, fulfill those functions specifically called for in the curriculum. There is little to say about this function except that in the future, as well as now, the better a person understands the curriculum and its components, the better that person will be able to serve these functions.

Ideally, the person applying the curriculum knows as much about the curriculum objectives and how students learn them as the curriculum developer. Rather than making leisurely, thought-out decisions about expectable students, however, the teacher must make quick decisions about real students who may vary from expectations in any number of ways. To do this well, he must understand the instructional tools he has at hand. One of the tools will be a computer. These are the kinds of actions we envision a teacher taking relative to the computer: substituting a non-computer alternative for a student who is having difficulty with a computer lesson, or vice versa, substituting computer for non-computer work; offering an explanation or supplementary instruction to get a student past a particular difficult point in a program; putting a student on a program out of normal sequence because of judged readiness; preparing supplementary instruction, such as paper-and-pencil practice problems, to be used in conjunction with a program; and so on.

Actually, these actions are the minimum we might hope for. Exactly what might be possible will depend on the flexibility offered the teacher by the developer. At one extreme, the teacher could be given a computer and a language and encouraged to program what is needed. At the other extreme, the teacher is given an immutable program with the simple choice for each program--take it or leave it. In most cases, something between these extremes would probably be optimal. That is, the teacher is given programs which can operate by themselves, but which allow him to access and modify major decision points. For example, a program might offer both demonstrations and practice of computational algorithms according to some decision procedure. The teacher could, if necessary, modify the program to give only practice and no demonstrations to a particular student. Without intervention, the program uses decision rules and teaching strategies which are hypothesized to be best on the basis of previous tests, but if any difficulties arise the teacher can make changes and still salvage that which is useful in the program.

Protagonists of CAI (e.g., Suppes & Morningstar, 1972) have argued that computers are not meant to replace teachers entirely but only to supplant them for a maximum of 30 percent of the time. Our view is different--we don't expect computers to replace teachers any more than textbooks do. A computer is a tool which extends greatly a teacher's potency. In using them well, a teacher will markedly improve the learning of his charges, but he will not save himself any time or effort. On the contrary, understanding and exercising the options offered by a computer will require more skill and effort on the part of a teacher.

Getting It Done. We would like to make some very brief additional prescriptions for materializing the vision. The necessary materials are people and machines. Consider first the people.

At the level of educational research and development, there are a great number of people doing important, influential work who would never dream of using a computer. Unfortunately, these people are given no encouragement to consider computers by those who know and are involved in CAI. Too often computers are represented as so complex and unique as to be beyond the ordinary mortal's grasp, and anything less than virtuoso performance at the computer is held to be trivial and wasteful of expensive machinery.

In order to integrate CAI into the educational world, it will be necessary to destroy this mystique of the computer. It is true that planning the use of a computer requires a certain amount of knowledge and appreciation for what a computer is and how it works, but this knowledge is not beyond the grasp of the intelligent non-expert. The technical details of how a computer accomplishes a set of actions need not concern the curriculum developer any more than the details of the printing process are a concern of the textbook writer. What the developer needs is first, a sense that computers are usefully under his control and then, some high-level knowledge with which he can exercise this control. It is up to those in CAI to educate and persuade their colleagues, who are working with more conventional materials, that computers are useful and realistic solutions to some of their problems.

Furthermore, people presently working in CAI need to confront the issues raised here. That is, they should begin to examine how the learning experiences they produce can be used in the context of complete curricula. Thus, we see a two-step process of change. First, those currently working with computers will expand their scope to consider how computers fit into the entire educational picture. Second, CAI people will begin to influence regular curriculum developers to use computers in the course of their work. This influence will come about by producing examples of good computer lessons (good not only in terms of internal logic but in terms of compatibility with total educational goals), by making a concerted effort to report this work to curriculum people (rather than CAI people), and by destroying the mystique of the computer and encouraging its general use.

Teachers will also need to be trained to understand and appreciate computers. Much of this training will also come from the demonstrations of good CAI examples, in this case aimed at teachers rather than purposely separated from teachers. In addition, with teachers there is already a formal training period in which they are taught the techniques of their profession. Computer instruction can easily fit into this period. Thus, we need to offer courses such as "Using the Computer in the Classroom" to prospective teachers just as they are presently given methods courses in other skill areas.

Finally, what kind of machines will be needed for the future? What our non-expert computer user of the future needs is a reliable, fairly easy-to-use system, and what he can afford to give up is extreme speed and sophistication in hardware. As Atkinson, Fletcher, Chetin, and Stauffer (1971) have argued, even simple machines are capable of very complex instructional strategies. A further requirement of an educational user of computers is that the system be easily used by young students. Most general-purpose systems which must accommodate other types of users do not meet this requirement.

There are two ways the general educational user of the future may get his machines. One is to plug into a large-scale system (such as PLATO IV) which is shared with many users but which is exclusively devoted to education. (For a discussion of this system, see Alpert & Bitzer, 1970.) The other way is to take advantage of the recent, and apparently continuing improvement in the performance and price of small to medium computing systems. The project at the Learning Research and Development Center has adopted the second strategy (Block, Carlson, Fitzhugh, Hsu, Jacobson, Puente, Roman, Rosner, Simon, Glaser, & Cooley, 1973).

This system is made up of a 32K Dec PDP-15 with high-speed drum and disk pack drive, and can drive 30 terminals simultaneously. The hardware was assembled for about $150,000, but could be duplicated today for as little as $60,000. Indications are that prices for such systems will continue to decline.

With this kind of a system, an educator can relatively quickly and inexpensively have terminals operating in a school. He would need a machine operator and at least one skillful program designer. Since we are attributing only rather general knowledge of computer operation to our educator, this designer will have to transform fairly vague specifications for lessons into actually operating programs--an ability requiring intelligence and sensitivity for educational concerns. One problem with small computers such as this is the availability of software systems suitable for educational uses. For our machine, we produced our own (Fitzhugh, 1973), but this will not be possible for most users. As demand increases for small computers in education, it can be anticipated that manufacturers will design appropriate software, just as software has been designed especially for bio-medical applications.

We take no stand on the superiority of the large system or small. The small computer has the advantage of being available here and now and of being more adaptable to particular educational needs. If there is great diversity in educational uses, it may not be possible to accommodate all of them on a large general system. The large system, when generally available, may well be cheaper and will require less attention from an individual user who, as we are arguing, should be attending to education and not to computer details. The future can easily accommodate both large and small computers.

Conclusion

If computers are to bring about a real improvement in education, then the existence of CAI as a separate field of endeavor must end. The goal of effective, adaptive, efficient education cannot be achieved by developing an isolated computer technology. This goal will be attained only by subjugating computer work to the larger endeavors of the psychological and educational disciplines which have been concerned with the problem of human learning.

The nature of future CAI development will be different than that of the present. Instead of setting out to teach what can be taught with a computer, the approach of the future should be to teach what needs to be learned and teach it as well as possible. Teaching well will depend on learning more about the learning process and on applying what we do know to produce good teaching. In our vision, computers will play a key role, but not a unique role, in both these enterprises. When we study how learning takes place, we will find computers most helpful. When we establish optimal teaching schemes, we will need to rely on computers as necessary components. But, in the future, no one will start out with a computer; he will start out with an educational problem--teaching reading, teaching problem solving, teaching physics. He will solve that problem with all the vision, creativity, and energy he can, and we are confident that that solution will involve a computer. But we are even more confident that that solution will be a greater contribution to education than any which is based on the premise that computers are a special, unique path to educational excellence.

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